JCAA/JGPP Lead-Free Solder Testing for High Performance Applications

Conclusions and Recommendations

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Results from individual tests (combined environments, thermal cycling and vibration testing) should not be used alone to make definitive decisions on Pb-free reliability. Results from this study should be taken as a whole.

Data Comparison BGA-225

Thermal Cycle -55/+125°C
SACB = SAC > SnPb

Combined Environments
SnPb > SACB = SAC

Vibration
SnPb > SACB > SAC

Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis

Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Therma Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-

Data Comparison CLCC-20

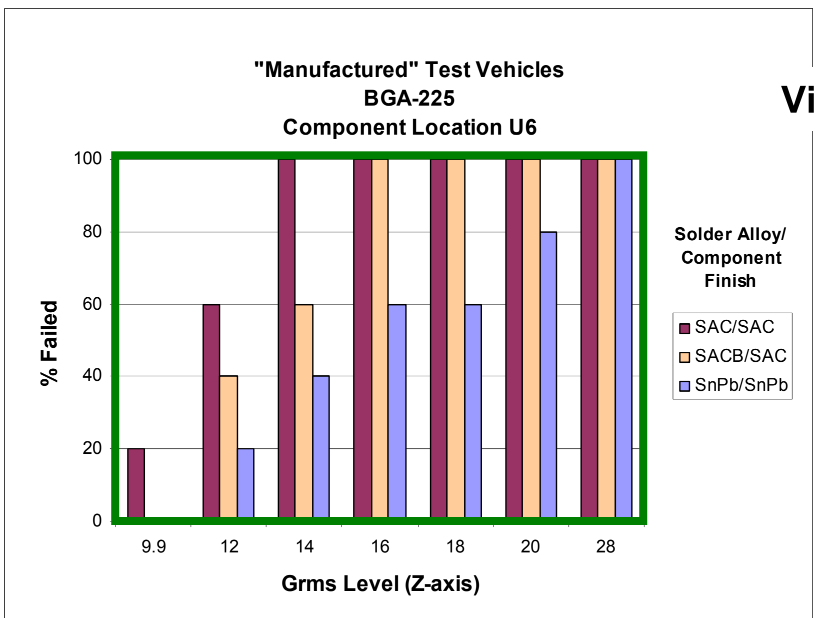
Thermal Cycle -55/+125°C
SACB > SnPb > SAC

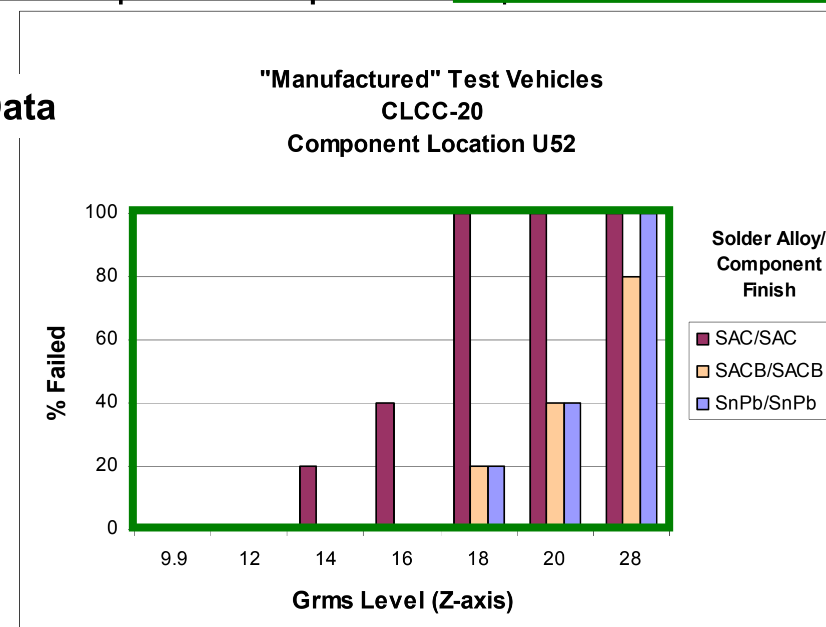
Thermal Cycle -20/+80oC
SAC = SACB > SnPb

Combined Environments
SACB > SnPb > SAC

Vibration
SnPb > SACB > SAC

Vibration Data





Component type has the greatest effect on solder joint reliability performance (greater than does solder alloy) for thermal cycling and combined environments. The plated-through-hole components are more reliable than the surface mount technology components for thermal cycling and combined environments.

Combined Environments

The PDIP-20 components experienced little or no failures.

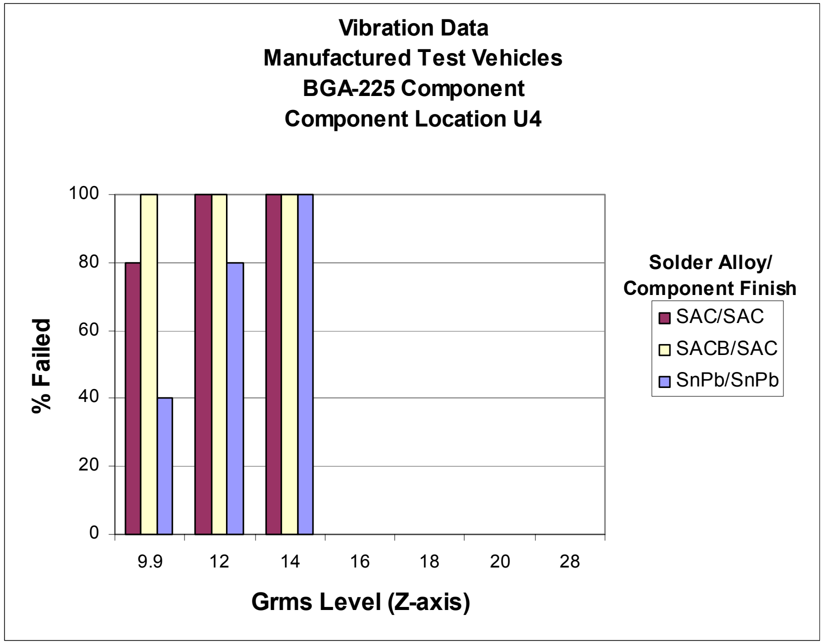
Component & Finish	Solder Alloy					
	SAC Paste	SAC Wave	SACB Paste	SnCu Wave	SnPb Paste	SnPb Wave
BGA SnAgCu	100% (25 of 25)		80% (20 of 25)			
BGA SnPb	96% (23 of 24)		84% (21 of 25)		76% (38 of 50)	
CLCC SnAgCu	100% (25 of 25)					
CLCC SnAgCuBi			80% (20 of 25)			
CLCC SnPb	100% (25 of 25)		100% (25 of 25)		100% (50 of 50)	
PDIP AuPdNi		0% (0 of 23)		4% (1 of 25)		8% (2 of 25)
PDIP Sn		0% (0 of 25)		4% (1 of 25)		0% (0 of 25)
PLCC Sn	0% (0 of 25)		0% (0 of 25)		0% (0 of 25)	
TQFP-144 Sn	56% (14 of 25)		32% (8 of 25)		32% (8 of 25)	
TQFP-208 AuPdNi	8% (2 of 25)		16% (4 of 25)		32% (8 of 25)	
TSOP SnCu	100% (25 of 25)		36% (9 of 25)			
TSOP SnPb	100% (25 of 25)		100% (25 of 25)		76% (38 of 50)	

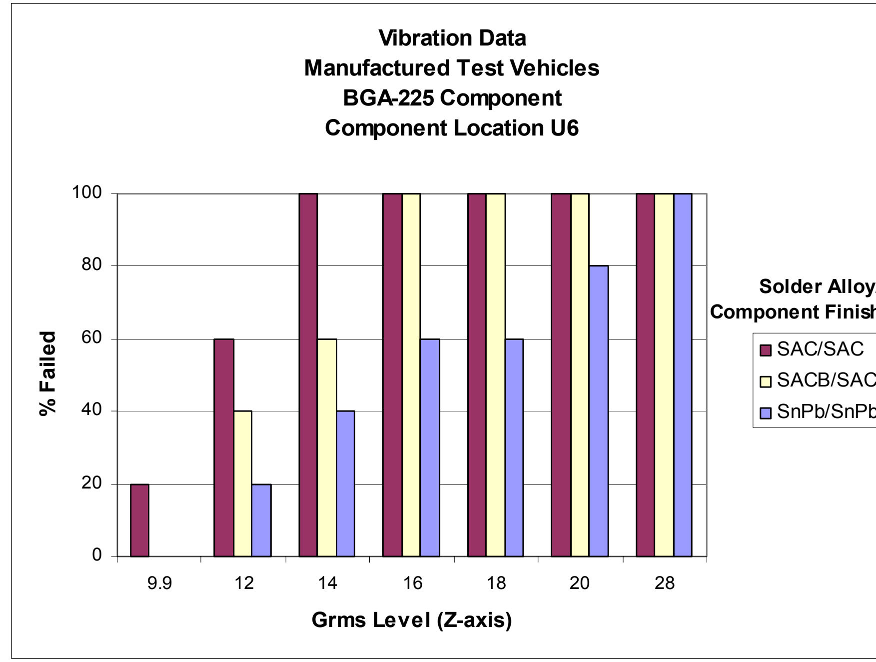
Thermal Cycle -55/+125°C

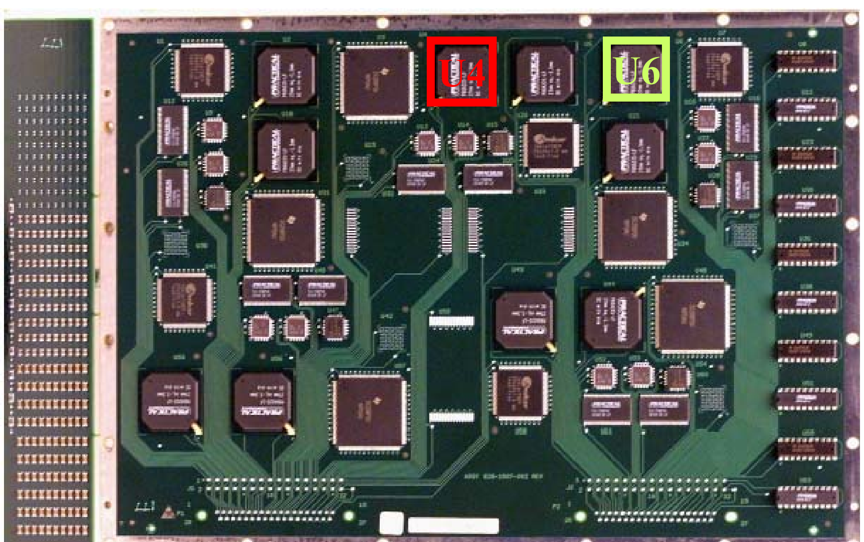
The PDIP-20 components failed 8% (24 of 300) of the total test population after 4743 thermal cycles.

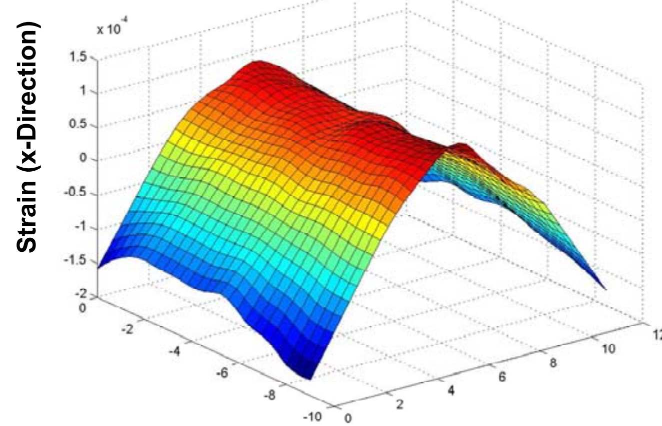
Component Type	Total Failures	Total Population	Percent Failed
BGA 225	257	300	85.7
CLCC 20	300	300	100
PDIP 20	24	300	8
PLCC 20	8	150	5.3
TQFP 144	136	150	90.7
TQFP 208	110	150	73.3
TSOP 50	296	300	98.7

Component location on the board has a significant effect on solder joint reliability performance for vibration.









PHANTOM WORKS

Mixed solder BGAs failed early for thermal shock.

Solder Performance -55 to 125°C Thermal Shock "Manufactured" Test Vehicles				
Component	Solder/Finish	1st Failure	N10	N63
CLCC-20	SnPb/SnPb	627	717	931
	SAC/SAC	79 (392)	477	681
	SACB/SACB	525	630	869
	SAC/SnPb	404	461	635
	SACB/SnPb	657	674	789
TSOP-50	SnPb/SnPb	961	NA	>1000
	SAC/SnCu	144, 278 (880)	NA	>1000
	SACB/SnCu	>1000	>1000	>1000
	SAC/SnPb	229, 250 (821)	NA	>1000
	SACB/SnPb	174	235	489
BGA-225	SnPb/SnPb	>1000	>1000	>1000
	SAC/SAC	>1000	>1000	>1000
	SACB/SAC	>1000	>1000	>1000
	SAC/SnPb	162	315	>1000
	SACB/SnPb	195	>1000	>1000

NA = Not enough failures to accurately determine

Solder Performance -55 to 125°C Thermal Shock "Rework" Test Vehicles				
Component	Solder/Finish	1st Failure	N10	N63
BGA-225	SnPb/SnPb	>1000	>1000	>1000
	SnPb/SAC	135	388	NA
CLCC-20	SnPb/SnPb	533	680	961
	SnPb/SAC	315	373	568
	SnPb/SACB	300	350	528
TSOP-50	SnPb/SnPb	596	829	1099
	SnPb/SnCu	565	778	1069
Reworked TSOP-50	SnPb/SnPb (After Rework)	415	463	978
	SAC/SnCu (After Rework)	783	826	1110
	SACB/SnCu (After Rework)	157	169	406
Reworked TQFP-208 (U3 Only)	SnPb/NiPdAu (After Rework)	>1000	>1000	>1000
	SAC/NiPdAu (After Rework)	182	200	675
	SACB/NiPdAu (After Rework)	17	19	150

NA = Not enough failures to accurately determine

The results of this study suggest that for some component types and environments, Pb-free solders are as reliable as the currently used eutectic SnPb solder. Unfortunately, this study also demonstrates that with other component types and environments, the Pb-free solders fail before the SnPb control.

Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis					
Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Thermal Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-
TQFP-144	SnPb/Sn	0	0	0	0
	SAC/Sn	P	--	-	NA
	SACB/Sn	P	++	0	NA
TSOP-50	SnPb/SnPb	0	0	0	0
	SAC/SnCu	++	--	--	NA
	SACB/SnCu	+	++	+	NA
	SAC/SnPb	+	--	-	NA
	SACB/SnPb	--	--	--	--
CSP-100	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	--	NT
	SACB/SAC	NT	P	--	NT
Hybrid-30	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	++	NT
	SACB/SACB	NT	P	++	NT

For many components SACB solder joints were at least as reliable as the SnPb controls during the combined environments and thermal cycling tests. (Exceptions were when SACB was contaminated with SnPb.)

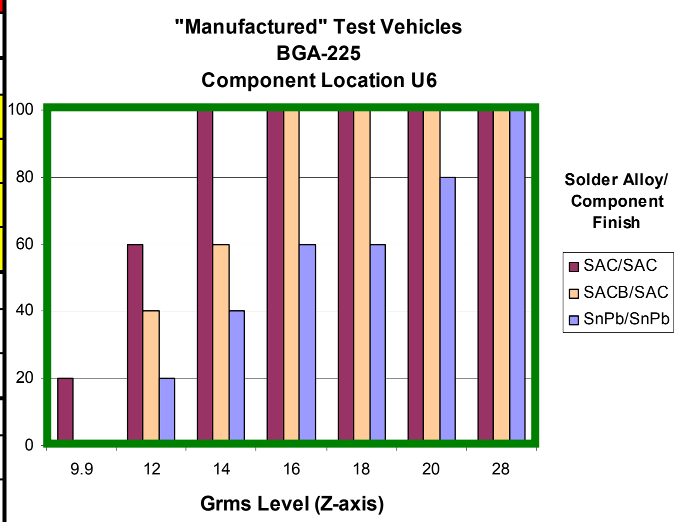
Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis					
Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Thermal Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-
TQFP-144	SnPb/Sn	0	0	0	0
	SAC/Sn	P	--	-	NA
	SACB/Sn	P	++	0	NA
TSOP-50	SnPb/SnPb	0	0	0	0
	SAC/SnCu	++	--	--	NA
	SACB/SnCu	+	++	+	NA
	SAC/SnPb	+	--	-	NA
	SACB/SnPb	--	--	--	--
CSP-100	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	--	NT
	SACB/SAC	NT	P	--	NT
Hybrid-30	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	++	NT
	SACB/SACB	NT	P	++	NT

The SAC soldered components were at least as reliable as the SnPb soldered controls for -20°C to + 80°C thermal cycling. However, SAC soldered components were often less reliable than the SnPb soldered controls during -55°C to +125°C thermal cycling, vibration and combined environments.

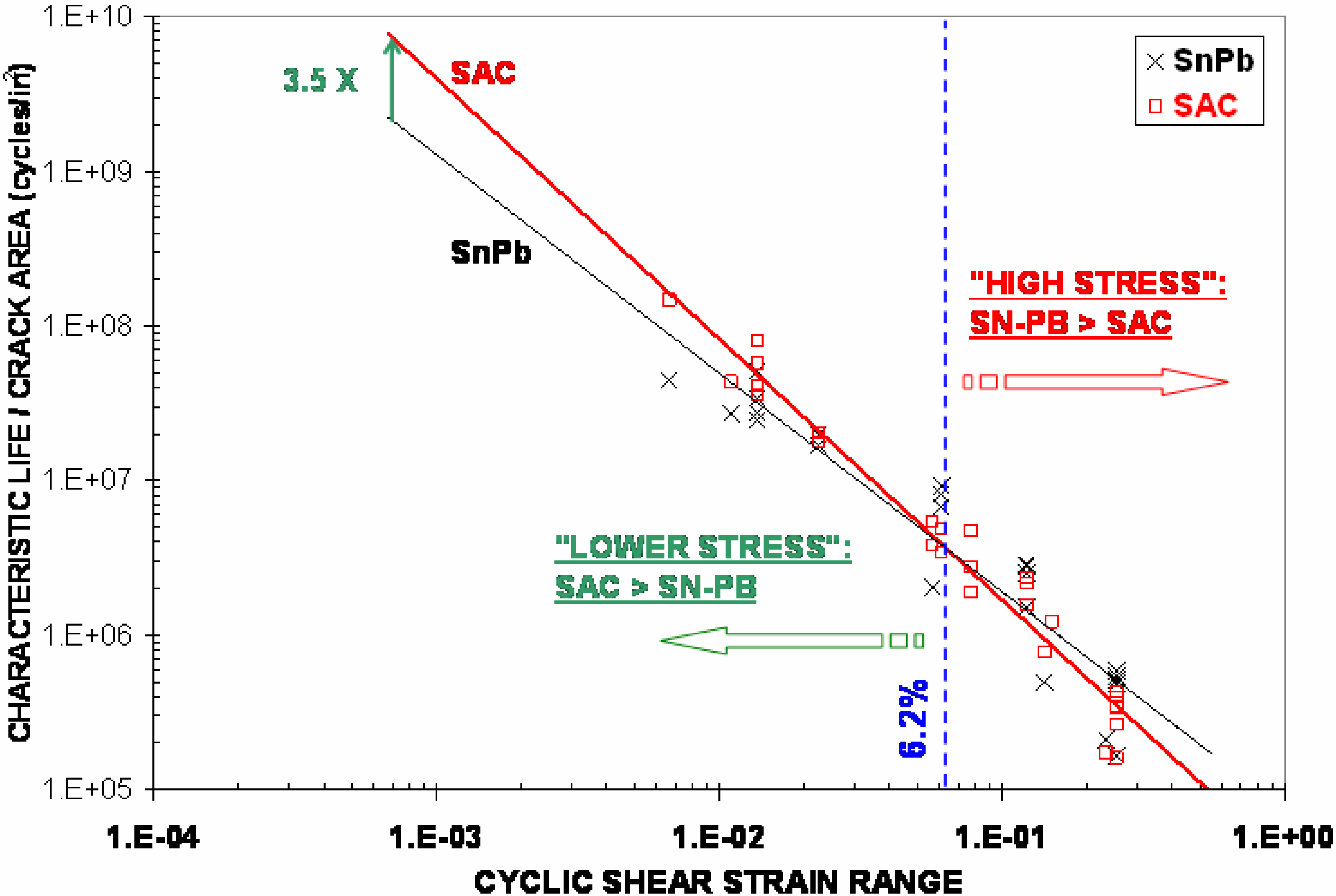
Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis

Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Thermal Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-
TQFP-144	SnPb/Sn	0	0	0	0
	SAC/Sn	P	--	-	NA
	SACB/Sn	P	++	0	NA
TSOP-50	SnPb/SnPb	0	0	0	0
	SAC/SnCu	++	--	--	NA
	SACB/SnCu	+	++	+	NA
	SAC/SnPb	+	--	-	NA
	SACB/SnPb	--	--	--	--
CSP-100	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	--	NT
	SACB/SAC	NT	P	--	NT
Hybrid-30	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	++	NT
	SACB/SACB	NT	P	++	NT

Vibration Data
SnPb>SACB>SAC



Under high-stress conditions, SnPb generally outperforms Pb-free. For low stress conditions, Pb-free generally outperforms SnPb.

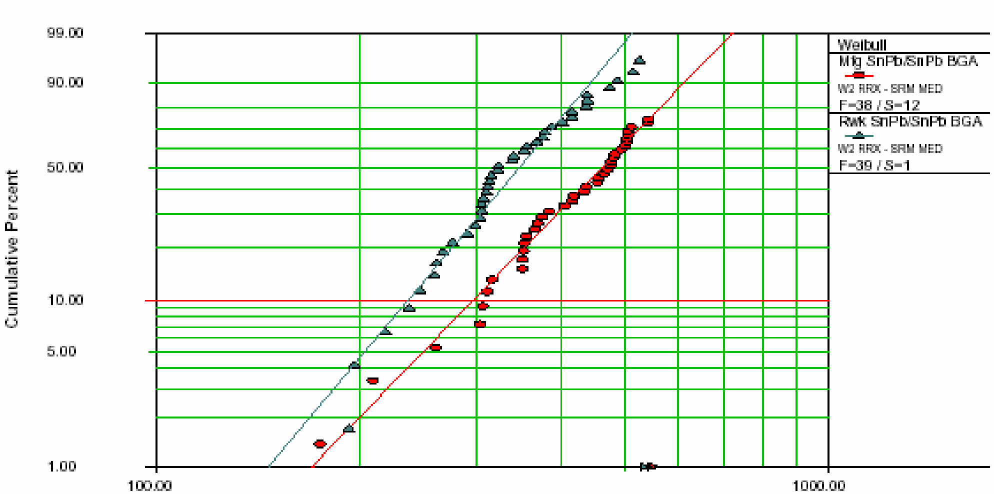


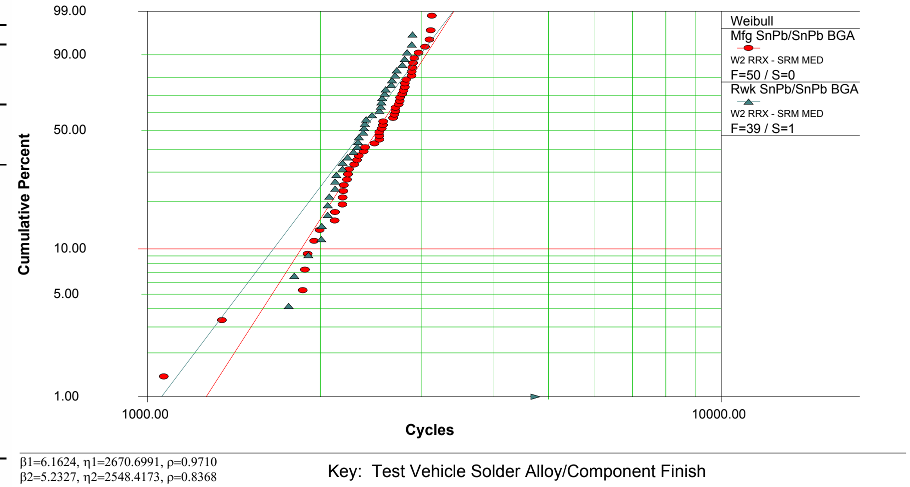
Reference: Clech, Jean-Paul, "Lead-Free and Mixed Solder Joint Reliability Trends", Proceedings of the IPC Printed Circuits Expo, APEX and Designers Summit 2004, February 24-26, Anaheim, CA (on CD).

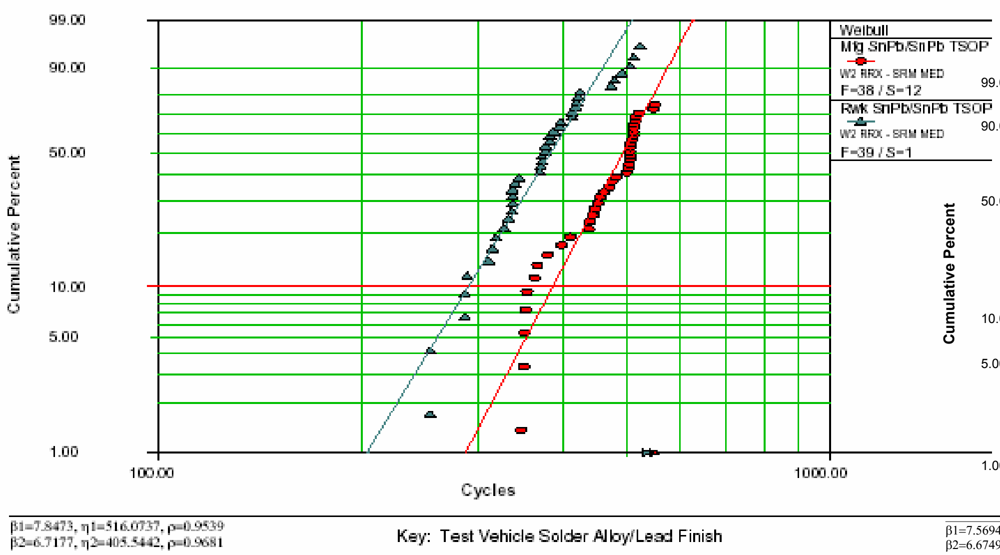
"Manufactured" (High T_g) SnPb solder joints outlasted "Rework" (Low Tg) SnPb solder joints during thermal cycling and combined environments testing. Therefore, PWB laminate characteristics (i.e., CTE and modulus) can be expected to affect the lifetime of Pb-free soldered hardware. For this study, one should exercise caution when comparing data from the "Manufactured" (High Tg) boards and the "Rework" (Low Tg) boards.

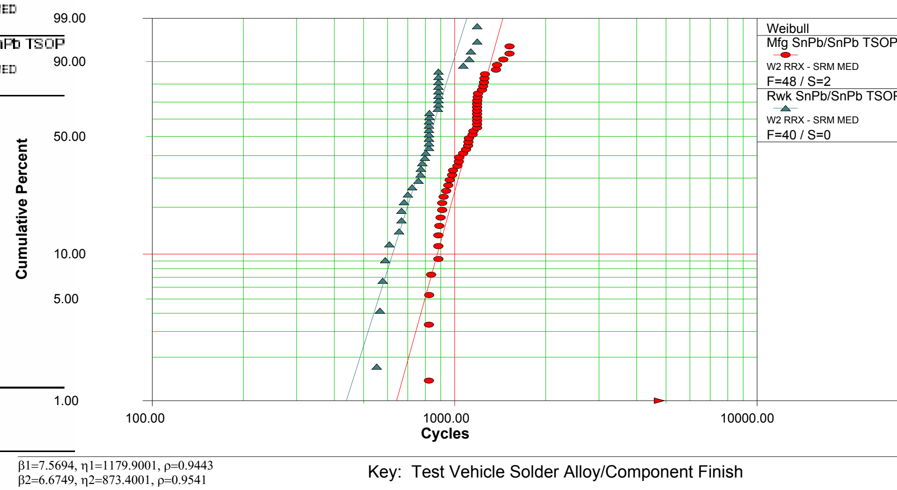
Combined Environments Data

Thermal Cycle-55/+125^{0}C Data







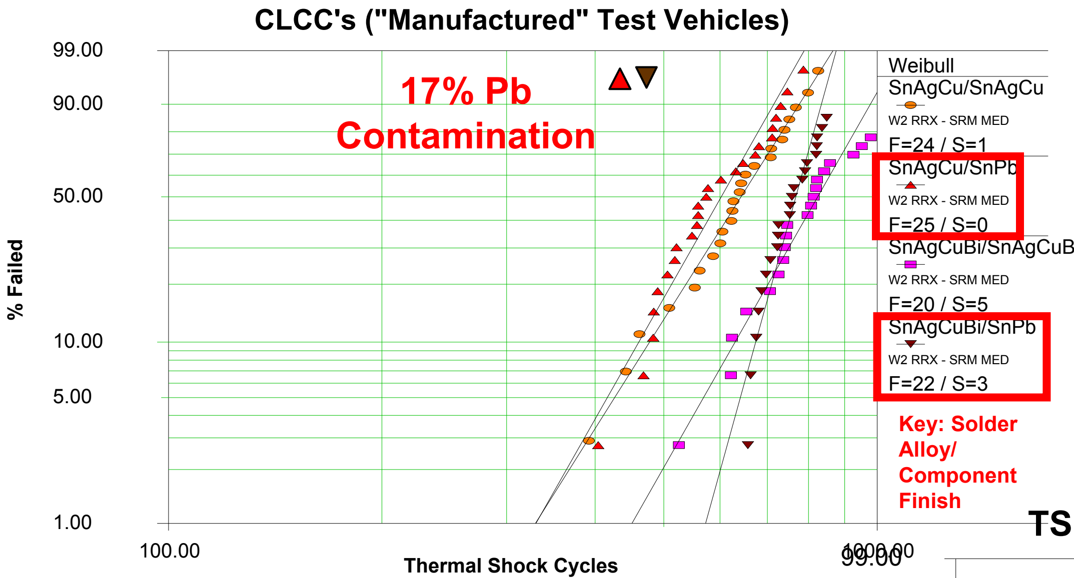


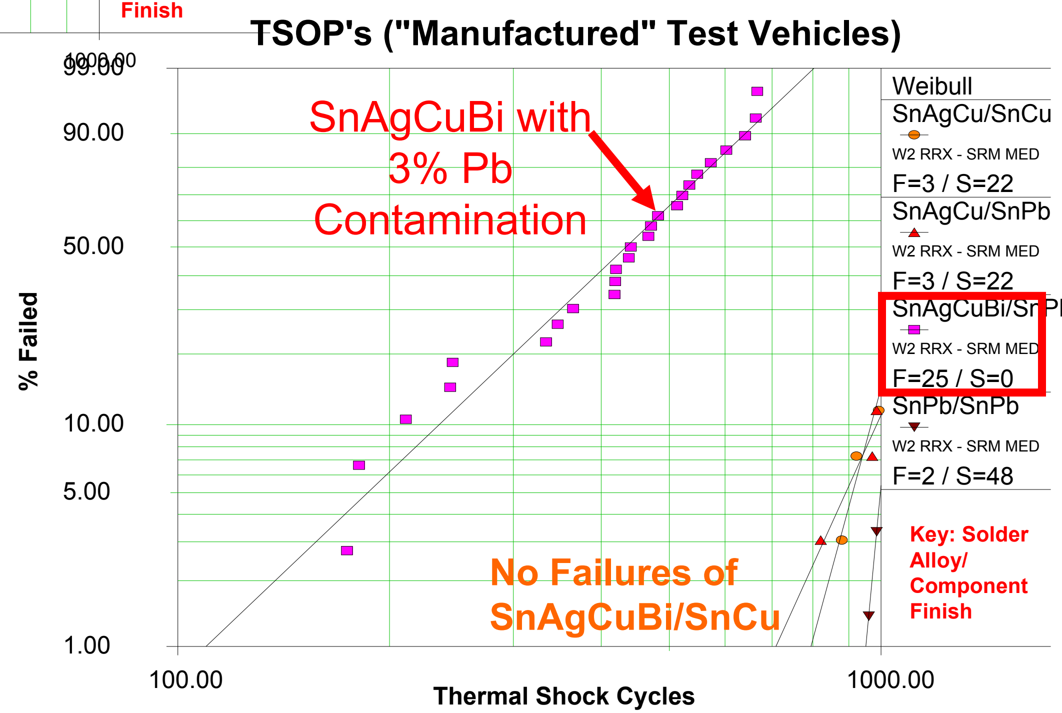
The impact of SnPb contamination on the Pb-free solder alloy reliability is mixed. For SAC, SnPb contamination can increase or decrease reliability. For SACB solder alloy, SnPb contamination usually has a detrimental effect on reliability. ***Continued on slide 11***

Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis

Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Thermal Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-
TQFP-144	SnPb/Sn	0	0	0	0
	SAC/Sn	P	--	-	NA
	SACB/Sn	P	++	0	NA
TSOP-50	SnPb/SnPb	0	0	0	0
	SAC/SnCu	++	--	--	NA
	SACB/SnCu	+	++	+	NA
	SAC/SnPb	+	--	-	NA
	SACB/SnPb	--	--	--	--
CSP-100	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	--	NT
	SACB/SAC	NT	P	--	NT
Hybrid-30	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	++	NT
	SACB/SACB	NT	P	++	NT

Continued from slide 10: The degree of degradation of SACB solder joint reliability appears to be inversely proportional to the amount of SnPb contamination in the solder joint. Therefore, soldering with SACB solder requires appropriate factory management to eliminate lead contamination.





Combined Environments Testing holds promise for replacing long term thermal cycling to accelerate the testing of future Pb-free solder alloys for some designs, especially if the general results and conclusions are similar to other tests.

Relative Solder Performance N10 for "Manufactured" and "Hybrid" Test Vehicles Based on Two-Parameter Weibull Analysis					
Component	Solder/Finish	Thermal Cycle -20 to +80°C	Thermal Cycle -55 to +125°C	CET	Thermal Shock
BGA-225	SnPb/SnPb	0	0	0	0
	SAC/SAC	P	++	--	NA
	SACB/SAC	P	++	--	NA
	SAC/SnPb	P	--	--	--
	SACB/SnPb	P	-	-	NA
CLCC-20	SnPb/SnPb	0	0	0	0
	SAC/SAC	++	--	--	--
	SACB/SACB	++	+	++	-
	SAC/SnPb	-	-	-	--
	SACB/SnPb	+	-	+	-
TQFP-144	SnPb/Sn	0	0	0	0
	SAC/Sn	P	--	-	NA
	SACB/Sn	P	++	0	NA
TSOP-50	SnPb/SnPb	0	0	0	0
	SAC/SnCu	++	--	--	NA
	SACB/SnCu	+	++	+	NA
	SAC/SnPb	+	--	-	NA
	SACB/SnPb	--	--	--	--
CSP-100	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	--	NT
	SACB/SAC	NT	P	--	NT
Hybrid-30	SnPb/SnPb	NT	0	0	NT
	SAC/SAC	NT	P	++	NT
	SACB/SACB	NT	P	++	NT

Recommendations

- The lower reliability of the Pb-free solder joints shown in some tests does not necessarily rule out the use of Pb-free solder alloy on aerospace and defense electronics in some use environments. However, models for calculating the actual field lifetime of Pb-free solder joints on certain component types must be developed and validated using actual test data (from this and other studies). These models can then be used to verify that electronics made with Pb-free solders will survive for the required lifetime in their use environments.

- The next logical step is system-level demonstration/validation of promising Pb-free solders on functional Class 3 aerospace and defense electronic systems. This will also help validate entire Pb-free assemblies in an operational environment.

- The tests in this study evaluated only solder joint reliability. Therefore, additional testing must be done to determine the effect of higher reflow temperatures on printed wiring boards and functional integrated circuits.

- Pb contamination must be better understood and controlled if SACB solder is to be utilized. The level of control of Pb contamination required when soldering with SACB may not be available to service centers and might pose an unacceptable risk to high-performance systems. If Pb contamination is not controllable, that may preclude the use of SACB solder on some or all aerospace and defense electronics.

- The results of this study should be used with other industry data as part of a comprehensive data set when considering Pb-free solder process implementation.